9. RADIATION SAFETY

This chapter addresses the radiological health and safety of workers during normal operations and anticipated events. The requirements for radiation safety are found in 10 CFR Part 20, *Standards for Protection Against Radiation,* and 10 CFR Part 70, *Domestic Licensing of Special Nuclear Material.* This chapter focuses primarily on occupational exposure during normal and anticipated abnormal events. Public and environmental protection is discussed in Chapter 10, and design basis accidents are discussed in Chapter 5.

The potential for occupational exposure at the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF) exists primarily as a result of the processing of plutonium (i.e., potential internal exposure from inhalation) and also as a result of handling other radioisotopes (i.e., direct external exposure). The primary design features that limit exposure in accordance with ALARA (as low as reasonably achievable) goals are confinement systems (e.g., gloveboxes, process cells, ventilation), monitoring, alarms, and radiation shielding. Confinement systems are described in detail in Section 11.4.

The design of the facility ensures that the total effective dose equivalent (TEDE) to individual members of the public from the MFFF will not exceed 100 mrem in a year from normal operations and anticipated operational occurrences. The design also ensures that annual occupational doses are maintained below a TEDE of 5 rem and 50 rem to any extremity.

The TEDE design goal for individual workers will be ALARA and less than 500 mrem/yr to most of the operating team members, with an extremity exposure goal of less than 10 rem/yr.

The annual occupational exposure limits from 10 CFR Part 20 are as follows:

- Total (CEDE + DDE) = TEDE 5 rem (0.05 Sv)
- Lens of Eye (LDE) 15 rem (0.15 Sv)
- Other Organs (CDE + DDE) 50 rem (0.5 Sv)
- Skin or Extremity (SDE) 50 rem (0.5 Sv).

Note: CEDE is committed effective dose equivalent; DDE is deep dose equivalent; LDE is lens of the eye dose equivalent; CDE is committed dose equivalent; and SDE is shallow dose equivalent. The extremities are considered to be the hand, elbow, arm below the elbow, foot, knee, and leg below the knee.

Potential occupational radiation exposure from exposure to external radiation sources is evaluated and minimized throughout the facility design process using three techniques: (1) general radiation zoning criteria, (2) the ABAQUES Method, and (3) design ALARA evaluations. The application of these criteria is sequential. The general radiation zoning criteria are established at the outset of the facility design. The ABAQUES Method is performed during the facility design, and the design ALARA evaluation is performed after the preliminary design. The design will be reviewed for ALARA concerns in accordance with 10 CFR Part 20 to ensure that exposures to workers are within the limits specified therein.

This chapter describes the design features of the MFFF and programmatic elements that together minimize occupational exposure.

9.1 RADIATION SAFETY DESIGN FEATURES

The MFFF design objectives ensure that operation of the MFFF is in accordance with 10 CFR Part 20 and the ALARA policy. Engineering features and controls are implemented during the facility design and operations to ensure that occupational doses are ALARA. The MFFF design objectives include, as a minimum, the following criteria:

- Integrating ALARA features based on experience from operating facilities into facility design and operating procedures with technological, economic, and social factors taken into consideration
- Maintaining radiation zoning criteria and design goals through access restrictions and shielding
- Estimating individual and collective doses to ensure the design provides for exposures to be ALARA
- Conducting periodic training and exercises for management, engineers, and designers in radiation protection principles and procedures, individual and group protective measures, specific facility procedures, and emergency response
- Integrating appropriate radiation protection controls into work activities.

9.1.1 ALARA Design Considerations

The purpose of this section is to summarize the elements showing that the design for construction and operation of the facility is adequate to protect the radiological health and safety of MFFF workers. The protection of members of the public and the control of effluent releases are discussed in Chapter 10.

The MFFF design reflects consideration of ALARA principles. Specific ALARA considerations in the MFFF design include the following:

- Control of plutonium particulate to prevent inhalation by confining radioactive materials in process equipment and in gloveboxes
- Multiple-zone ventilation system design
- Continuous remote monitoring of airborne conditions in the access areas
- Use of automated and remotely operated equipment to minimize personnel exposure
- Removal of radioactive sources before most maintenance operations
- Placement of radiation shields between radioactive sources and the operators according to the intensity, nature, and penetrating power of the radiation
- Design of structures, systems, and components (SSCs) that require a minimum of maintenance or repair to minimize personnel stay times in radiation areas

- Placement of administrative, security, and radiation protection activities away from radiation areas
- Use of area radiation monitoring with local and remote readouts and alarms to inform personnel of changing conditions.

9.1.1.1 Organizational Relationships and Responsibilities for ALARA Design

The MFFF Engineering Manager is responsible for the implementation of radiation protection design criteria. The MFFF Facility Design function includes responsibility for the integrated design of the facility and reports to the MFFF Engineering Manager.

The design organization employs personnel qualified in radiation protection design and ALARA concepts, including personnel experienced in radiation protection, radiation shielding, and general radiation safety. Design personnel are trained to recognize potential radiation hazards and to minimize the effects of these hazards on operations.

The primary radiation analyses performed in support of the radiation protection design are radiation shielding calculations and occupational radiation dose assessments.

9.1.1.2 Design-Stage Collective Dose Estimates

The design process includes an estimate of the occupational dose assessment for the facility. ALARA evaluations are performed and documented to determine cost-effective design enhancements to reduce exposures. Dose assessments are performed using Regulatory Guide 8.19, *Occupational Radiation Dose Assessment in Light-Water Reactor Power Plants, Design Stage Man-Rem Estimates*, and Regulatory Guide 8.34, *Monitoring Criteria and Methods to Calculate Occupational Radiation Doses.*

For the license application for possession and use of special nuclear material (SNM), the dose assessments will take into account both direct and internal dose. The direct dose assessment is determined by dose rate analyses and the ABAQUES Method described in Section 9.1.2.3.2. The internal dose assessment is determined based on the MFFF design and review of MELOX experience (Section 9.1.2.4). The internal dose will be added to the direct dose. This sum is compared to the 500-mrem/yr goal to maintain exposures ALARA.

Cumulative doses are estimated at this stage in Section 9.1.2.4, based on the comparison of MELOX and MFFF source terms and MELOX operating experience.

9.1.1.3 Design Review Process

Competent personnel are responsible for the review of, and concurrence on, preliminary and final designs. The design reviews incorporate the experience from MELOX and La Hague. The project design reviews include ALARA evaluations of designs that may lead to high occupational exposures. The design team tracks the recommendations included in the evaluations to completion.

Continuing radiation safety (ALARA) design reviews for facility or process modifications will be conducted during construction and operations. An appropriately qualified organization will be responsible for reviewing facility or process modifications for the express purpose of maintaining exposures ALARA.

9.1.1.4 Past Experience

The MFFF design incorporates applicable experience from MELOX and La Hague for radiation protection, such as the following:

- Descriptions of process unit operations
- Personnel access times
- Source configurations
- Radiation dosimetry
- Radiation exposure problem areas
- ALARA design features and performance
- Contamination estimates
- Radiation monitoring design and operations
- Process unit shielding design.

Much of the MFFF facility design is the same as that used at the MELOX facility. Therefore, the occupational exposures should be similar with adjustment for the difference in the radiation source terms.

9.1.1.5 Other Design Considerations

The design reduces the time spent in radiation areas by incorporating design features of the MELOX and La Hague facilities. The zone classification of the facilities provides information to the designers for minimizing occupational radiation exposure through access control and shielding design to meet exposure criteria.

The design provides for the accessibility of components requiring routine maintenance or in-service inspection by using gloveboxes as described in Section 9.1.4.2.

The design minimizes the distribution and retention of radioactive materials throughout plant systems by:

- Designing the process equipment containing the radioactive materials so as to confine them to the maximum extent practical and reduce glovebox contamination
- Designing the gloveboxes to prevent accumulation of contamination and allow easy access for cleaning
- Using a vacuum system in gloveboxes as necessary so that airborne dust is collected in dust pots in the concerned gloveboxes and the material is recycled.

The project conducts ongoing training for designers and engineers in ALARA design objectives. Designers and engineers are aware of ALARA design objectives. This awareness ensures that

ALARA features are incorporated into the design as it is being developed, before radiation protection engineers review the design for the express purpose of ensuring that it meets ALARA design objectives.

As described in Section 9.1.1.4, experience from the MELOX and La Hague facilities is incorporated into the design to ensure that the total exposure from the MFFF is maintained ALARA. Airborne contamination and loose surface contamination are prevented during normal operations by the glovebox and ventilation system design to maintain inhalation dose ALARA.

Radiation protection design improvements that have been made at the MELOX and La Hague facilities are incorporated into the MFFF facility design. For example, the Grinding Unit vacuum system minimizes loose contamination in the glovebox. Project team members have direct experience with those facilities, and design documentation is available to the design team for this project to consider and incorporate to the maximum extent practical.

9.1.2 Facility Design Features

This section describes the primary design features and equipment that directly or indirectly reduce radiation exposure for facility workers and provide monitoring capability.

9.1.2.1 Equipment and Facility Design Features

The greatest potential for occupational radiation exposure is from plutonium inhalation. Therefore, the design incorporates multiple systems and barriers to prevent releases to personnel access areas. Depending on the stage in the process, confinement of radioactive materials and worker protection are obtained by process vessels in cells (aqueous polishing [AP]), gloveboxes (Powder Area and Pellet Process Area), or sealed envelopes (rods, containers) (see Section 11.4). Sealed gloveboxes are used to prevent personnel contamination. The gloveboxes are kept at a negative pressure with respect to the area occupied by personnel to ensure that contamination would be contained in the event of a breach. A second ventilation system in the cell forces air down from the ceiling to the floor to minimize the potential for inhalation in the event of a glovebox breach. Airborne contamination and pressure are monitored to detect changes in the containment barriers.

A second source of potential occupational radiation exposure is from direct exposure to radiation sources within the gloveboxes. Although exposure rates are low, various design features have been implemented to attenuate ionizing radiation and to further limit operator exposures, including (1) limiting exposure times through automation and remote control of production workstations, and (2) placing shielding between radiation sources and operators according to the radiation intensity.

For the AP Area, the primary feature is the remote operations capability (see Section 11.3). Few operations are performed in the radiation area. System sampling and inspections are designed to be performed from access areas outside of the high radiation areas. Sources of radiation are removed from the work area prior to extensive work being performed. For process cells, routine access is precluded and radiation shielding is made up by the cells' concrete walls.

For process rooms containing gloveboxes, few operations are performed in the process rooms themselves, so free access is not necessary. The areas around the process rooms are protected against direct radiation by the rooms' concrete walls. Radiation shielding is implemented on the gloveboxes as necessary, and the facility is designed so that sources of radiation can generally be removed from the work area prior to extensive work being performed.

MOX Processing (MP) Area work is primarily performed from the process rooms, so these rooms are accessed routinely. Radiation and pressure monitoring are performed to detect changes in the confinement barriers. Shielding is designed so dose rates in radiation work areas are low to accommodate the required access. Existing data from the MELOX and La Hague facilities are used to estimate the access requirements for the facility. Dose rates based on MFFF source terms are used to show the low occupational doses expected for this facility. Where gloveboxes are present for radioactive material confinement, radiation shielding for both neutron and gamma sources is designed permanently into the glovebox system (inside the glovebox for large radiation sources when this does not impair operation, and outside the glovebox whenever practical). Shielding is separate from the confinement barrier to allow for changes, if needed, without the potential for contamination spread. The radiation shielding concepts in the MFFF include the following:

- **AP cells** – thick concrete walls constitute the primary shielding
- **AP gloveboxes** –shielding on the gloveboxes as needed; locked doors to the cells
- **MP gloveboxes** – internal shielding inside the gloveboxes whenever practical; external shielding outside the gloveboxes in general
- **MP areas** – separate cells for each process unit shielded by concrete and sealed to prevent the spread of contamination.

The glovebox design incorporates the use of shielding to protect workers from direct radiation. Interior shields are provided to ensure that radiation from specific sources is minimized. Glovebox walls incorporate appropriate shield materials to reduce worker exposures. Regular glovebox maintenance is scheduled to minimize radiation exposures to the maintenance personnel and to limit the potential for a release of airborne radioactive material.

9.1.2.2 Design Features to Reduce Contamination and Waste Production

Many of the design features addressed in the previous section perform contamination control functions. In addition, the design reduces the distribution and retention of radioactive materials throughout plant systems by using a vacuum system in gloveboxes as required. Airborne dust is collected in dust pots in gloveboxes, as necessary, and the material is recycled.

Design features will control contamination so that secondary waste production is minimized. The design features ensure that contamination is isolated to specific areas and that contamination is minimized at the time the plant license is terminated. The design incorporates extensive recycling for the materials exiting the main process (i.e., secondary waste streams of the AP process, scraps not meeting specifications in the MP process). The recycling process is designed to minimize the quantity of plutonium in the final waste by using systems that process the

radioactive materials and send them back to previous steps of the main process, as described in Sections 11.2 and 11.3.

9.1.2.3 Facility Design Goals

The general design requirements established for the various radiological attributes addressed below include those that maintain exposures ALARA during normal operations of the facility and minimize exposures during off-normal conditions.

Potential occupational radiation exposure from exposure to external radiation sources is evaluated and minimized throughout the facility design process using general radiation zoning criteria, the ABAQUES Method, and design ALARA evaluations.

9.1.2.3.1 Radiation Zoning

Preliminary radiation zoning is developed based on estimates of the access required for each zone and radiation dose limits for personnel from 10 CFR Part 20. Shielding for the process units and access areas is designed to satisfy these preliminary radiation zoning criteria. The final dose assessment verifies that the facility can be operated within the occupational exposure limits of 10 CFR Part 20 and ALARA principles.

The design criteria for occupational exposures inside the MFFF are supported by the radiation zone limits presented in Table 9-1.

In zones Z1 and Z2, residence time is not restricted. The design basis maximum area radiation dose rates shown on Figure 9-1 allow continuous occupancy. The design basis maximum area radiation dose rate limit is the only shielding design criterion. Residence time is restricted in zones Z3, Z4, and Z5 of the AP Area, and access is permitted only for maintenance or intervention.

Access to Z3 process rooms in the MP process areas is necessary for normal operations and routine maintenance. The annual dose equivalent for workers is evaluated by the ABAQUES Method (see Section 9.1.2.3.2) using reasonable assumptions (in the form of time-motion studies). Access to zones Z4 and Z5 is restricted for nonroutine maintenance or intervention.

Radiation zones are shown in Figures 9-1 through 9-9. The blue zone, Z1, is a continuous occupancy area for staff and visitors. The green zone, Z2, is a continuous occupancy area for trained workers. The yellow zone, Z3, is a limited occupancy area in which routine maintenance may be performed by trained workers. The orange zone, Z4, and red zone, Z5, are conservatively estimated and are expected to be high radiation and very high radiation areas, respectively. Detailed shielding analyses will be conducted in the final design phase of the project with the results provided in the license application for possession and use of SNM.

9.1.2.3.2 The ABAQUES Method

The facility design and resultant occupational dose are evaluated using the ABAQUES Method, which is similar to that provided in Regulatory Guides 8.19 and 8.34. Radiation shielding is selected to minimize personnel occupational exposures based on facility occupancy for normal

operations and facility maintenance. Personnel exposures are estimated based on facility experience for access requirements, and standard shielding methods are used to estimate radiation fields. The method is iterated to minimize the number of personnel that have the potential of receiving more than 500 mrem/yr. The general equation that is used to satisfy this prerequisite is as follows:

$$\frac{\sum_i f_i \times t_i \times DER_i}{\sum_i f_i \times t_i} \leq \frac{500\,mrem/yr\,(\text{design objective for individual doses})}{T} \qquad (9\text{-}1)$$

where:

f_i = the frequency of each task associated with a given process unit or group of process units

t_i = the time of exposure for the task

DER_i = the dose equivalent rate for the task

T = the average estimated annual working time in radiation zones

$\sum_i f_i \times t_i$ = the total yearly duration of all of the tasks performed by the same work group associated with the process unit or group of process units.

The *DER*s are adjusted by varying the shielding thickness, and/or the operating conditions (operation duration and frequency) are changed to reduce the exposures to below the 500-mrem/yr goal. The *T* is an estimate of the average time an individual spends in the radiation area per year based on industry operating experience.

9.1.2.3.3 ALARA Evaluations

This process includes a preliminary estimate of the occupational exposure, an ALARA evaluation of the activities that produce exposures, and recommendations for design enhancements to reduce occupational exposures. Lessons learned from facility operations and industry guidance are used to evaluate potential design enhancements. ALARA cost-benefit analyses are performed to support design enhancements using NUREG/CR-0446, *Determining Effectiveness of ALARA Design and Operational Features.*

Preliminary occupational exposure data based on data from MELOX are estimated. These data are used during the preliminary design phase to evaluate occupational radiation exposures and to recommend potential enhancements to the design to effectively reduce doses. Final design shielding calculations are performed to estimate dose rates and doses using the ABAQUES Method.

9.1.2.4 Predicted Occupational Doses

Occupational exposures will be estimated for the MFFF facility in order to perform ALARA evaluations as described in Section 9.1.2.3.3. Dose rates from shielding analyses are combined

with access requirements and/or time-motion information from MELOX and La Hague. These results are evaluated to determine if design enhancements are needed to further reduce exposures ALARA. This work will be summarized in the license application for possession and use of SNM.

9.1.2.4.1 Dose Assessment Estimate

A preliminary estimate of the facility occupational exposures is made based on MELOX experience with adjustments for source term differences, but assuming consistent shielding. At the MELOX facility, photon and neutron radiation accounts for approximately 40% and 60%, respectively, of the total radiation dose. (Internal exposure represents only a fraction of total dose.)

As discussed in Section 9.1.3.3, the ratio of the MELOX photon dose to the MFFF photon dose is approximately 20:1, and the neutron dose ratio is approximately 11:1. Using these ratio data, the occupational exposures at the MFFF can be estimated. This estimate assumes that the same equipment is used with the same shielding and that similar personnel access is required.

Inhalation dose contributes less than 4.5 person-rem per year (assuming the full 50-year dose commitment in the year of exposure). The direct dose estimate is expected to be approximately 12 person-rem per year, while the total dose is estimated to be below 20 person-rem per year.

The final dose assessment will incorporate input from the shielding analysis and personnel access requirements based on existing facility experience and the MFFF design. This information will provide the data necessary for performing ALARA evaluations during the final design phase.

9.1.2.4.2 Contribution from Internal Exposure

There are two primary sources of radiation risk to the MFFF worker: plutonium inhalation and direct radiation exposure. Plutonium inhalation is the most significant potential hazard at the facility. Design engineers are instructed on the risks and the methods of controlling plutonium contamination. The Powder Area and Pellet Process Area have the greatest potential for generating respirable particulate, releasing contamination, and causing worker inhalation exposure. These process areas provide radiation protection through multiple system barriers and controls:

- The operations for the units are controlled remotely and are automated to minimize access to the work area.
- The plutonium is contained in a sealed glovebox. This internal environment is kept under negative pressure relative to the worker environment. Any leakage in the glovebox would be from the work area into the glovebox, thus preventing the release of contamination.
- Pressure within the glovebox is monitored, and a lighted signal indicates system operability.
- Glove ports are provided for maintenance access to the process equipment.

- Dedicated preventative maintenance is performed in the absence of process material to the extent practical to further reduce the hazard to the worker.
- Radiation monitoring of the air environment is provided at the work location with alarms at low setpoints to cause evacuation from the work location if contamination is detected.

Potential loss-of-confinement events are analyzed so that systems can be designed to minimize the likelihood and consequences of such events. The confinement systems are protected against damage from internal and external events to minimize the possibility of failure. The structure is designed to withstand the effects of natural phenomena hazards. Internal events that could compromise the integrity of the confinement system are prevented by the design.

Events that are expected to occur over the lifetime of the facility and their consequences are estimated and added to occupational exposure estimates. Total exposures are designed to be within the limits of 10 CFR Part 20.

Review of MELOX operating history indicates that, in eight years, there have been 12 reportable instances. These events were not significant (i.e., none at level 2 or greater on the International Nuclear Event Scale [INES]). Design and management measures at MELOX are similar to MFFF; thus, the normal internal exposure received at MELOX, which is a fraction of the total dose, is assumed to represent a reasonable estimate for the MFFF.

The INES uses an eight-level system to rate events: 0 to 7, with 0 being the least severe and 7 being the most severe. The events at the MELOX facility and their corresponding INES ratings are provided in Table 9-2. Based on the INES rating system, level 0 events are those events classified as being without safety significance (i.e., low consequence to the worker). Level 1 events are classified as anomalies. Level 2 events are classified as events resulting in worker exposure over the occupational limits set by 10 CFR Part 20. There have been no level 2 (or greater) events at the MELOX facility during its operation.

In conclusion, although events that result in loss of confinement may occur during the operating life of the MFFF facility, as evidenced by the MELOX model, such events are expected to be infrequent and result in low consequences to the worker based on system design. The cumulative dose potential is insignificant compared to the direct dose contribution.

9.1.2.5 Facility and Process Drawings

Chapter 11 includes facility and process drawings and descriptions. Further information will be provided with the license application for possession and use of SNM. Drawings, process descriptions, and other plant documentation to be maintained at the MFFF include the following:

- Scaled drawings
- Features relied upon to reduce doses to meet the requirements of 10 CFR Part 20 during routine and non-routine operations (including anticipated events)
- Locations of detectors and alarm systems
- Locations of permanent shielding (e.g., penetrations, labyrinths, shield doors)

- Provisions for installation/removal of temporary shielding
- Locations and access control points for radiation areas
- The controlled area, including the means to limit access to the controlled area as necessary
- The restricted area (coincident with the protected area shown on Figure 1.1-2)
- Change rooms, showers, and locker rooms
- Contamination control and waste minimization design features.

9.1.2.6 Self-Assessment

Self-assessment of the facility design, shielding, traffic patterns, expected maintenance, and sources to determine that both collective and individual doses are within the limits of 10 CFR Part 20 will be addressed in the license application for possession and use of SNM. The self-assessment will address these items against the facility design goals for routine and non-routine operations, including anticipated events.

9.1.2.7 Worker Access Controls

Worker access controls for high and very high radiation areas that will meet 10 CFR §20.1601 and §20.1602, respectively, will be discussed in the license application for possession and use of SNM. Change rooms are provided as addressed in Section 9.1.2.10.

9.1.2.8 Health Physics Counting Equipment

MFFF Health Physics equipment comprises a broad spectrum of analytical instruments used to determine the presence of radioactive material and to quantify the amount of contamination. The instrumentation ranges from gross measurements to specific isotopic analytical analyzers that can determine the constituents and quantity of each isotope. The instrumentation also includes installed personnel monitors and hand-held survey equipment.

9.1.2.8.1 Alpha/Beta Counters

Due to the nature of the radioactive material at the MFFF, the ability to detect minute quantities of plutonium requires the use of sensitive equipment. The MFFF radiation protection equipment will be capable of detecting extremely low levels of alpha contamination in a relatively short counting time cycle. The selection process centered on instruments with a high sensitivity toward alpha particles while still being capable of detecting beta contamination for the incoming radioactive material.

Each Health Physics laboratory (MP and AP) will be equipped with at least two alpha/beta counters to enable the processing of swipes and airborne contamination surveys on a continuous basis without interruption. Additional counters are located within the MP Area to support incoming radioactive material and shipments of waste, fuel, and excess materials.

9.1.2.8.2 Isotopic Analytical Equipment

Each laboratory will be equipped with instrumentation capable of quantifying the radioactive material on swipes, air samples, and any other sample configuration. The detector portions of the instrumentation will be installed in counting shields to reduce any background effects and minimize background counts.

9.1.2.9 Personnel Monitoring Equipment

9.1.2.9.1 Hand and Foot Monitors

Each transition between confinement zones, as defined by the ventilation system areas in Chapter 11, requires personnel to monitor for contamination. To provide for this transition, airlocks are installed between confinement zones, as well as in areas where there is a potential for the spread of contamination. Each airlock is provided with personnel monitoring equipment to ensure that contamination is controlled as close to the source as physically possible.

9.1.2.9.2 Installed Survey Instruments

Each airlock and glovebox has an installed survey meter to ensure that personnel perform a thorough survey before exiting the work area and the confinement zone. The survey meters, commonly named "friskers," are counters with a high efficiency for alpha detection. Placement of the friskers is based on providing personnel with an instrument as close to the work area as possible. By placing detectors on the gloveboxes, personnel are able to survey their hands as soon as they remove them from the glove ports. This capability enables the control of potential contamination as close to the source as possible.

The hand and foot monitors and friskers are equipped with alarm circuits to provide indication of personnel contamination in the Health Physics offices. If an individual alarms either of the instruments during a survey, Health Physics personnel are dispatched to the location to minimize the spread of contamination and to decontaminate the individual and the area.

9.1.2.9.3 Personnel Contamination Monitors

Prior to exiting the production areas of the MFFF, personnel are required to be surveyed to ensure that no contamination leaves the facilities. Personnel contamination monitors (PCMs) are installed at the access control point so that personnel have to be surveyed prior to leaving the airlock. The monitors consist of multi-detector instruments that allow an individual to be monitored over their entire body in a relatively short time period.

9.1.2.10 Health Physics Working Spaces

9.1.2.10.1 MOX Fuel Fabrication Building

The Health Physics working spaces in the MOX Fuel Fabrication Building are shown on the general arrangement drawings and consist of two radiation protection laboratories, which will contain instruments and areas where technicians may prepare their survey results and store hand-held instruments. These laboratories will contain multi-sample alpha/beta counters, as well as

hand-held survey instruments and portable air samplers. One laboratory will contain an isotopic analyzer. The space will allow personnel to perform surveys, count the samples, perform isotopic analyses, and record results.

9.1.2.10.2 Aqueous Polishing Area

The radiation protection working spaces in the AP Area are shown on the general arrangement drawings and consist of two rooms (i.e., radiation protection laboratory and radioprotection storage room) assigned for the placement of instruments and areas where technicians may prepare their survey results and store hand-held instruments.

The radiation protection laboratory will contain multi-sample alpha/beta counters, as well as the isotopic analyzer. The space will allow personnel to count samples and to perform an isotopic analysis of the samples as necessary.

The radioprotection storage room will contain survey and sampling equipment, as well as necessary Health Physics support equipment, consisting of the equipment necessary to support maintenance activities in the AP Area.

9.1.2.10.3 Shipping and Receiving Area

The Shipping and Receiving Area contains the access control point, which serves as the egress point for both the MP and AP Areas. This area has the PCMs and the Decontamination Area / Contaminated First Aid Room. The Decontamination Area / Contaminated First Aid Room contains a shower and sinks to perform minor decontamination of individuals and treat minor injuries.

The readout and alarm monitors located in the Polishing Utilities Control Room and the Respirator Maintenance/Health Physics Room present the alarms and radiation levels for the radiation monitoring equipment. These visual displays provide for the identification of specific alarms and the locations of the monitors in the workplace for the area radiation monitors (ARMs), continuous air monitors (CAMs), criticality monitors, friskers, hand and foot monitors, and PCMs.

The monitoring system uses trending software to identify increasing direct radiation levels over a period of time. The system provides the initial warning of increasing radioactivity in gloveboxes and production rooms and releases to the environment.

9.1.2.10.4 Technical Support Building

The Technical Support Building has three rooms dedicated to Health Physics activities:

- **Respirator Maintenance and Health Physics Room** – This room is designed to house the respirator equipment and issue area for the MFFF. This room provides for the minor repair of respirators and storage of spare equipment and emergency supplies.
- **Clean Anti-Contamination Storage Room** – This room provides for the storage of anti-contamination clothing for use during maintenance activities.

- **Technical Support Building Locker Rooms and Change Areas** – These areas contain storage racks for respirators and dosimetry devices. Personnel are able to obtain their respirator and alarming dosimeter, and log in on the appropriate Radiation Work Permit (RWP) prior to transiting to the MFFF. Space is provided for an increase in staff during maintenance outages.

Maintenance activities are performed in local enclosures, and personnel change into appropriate protective clothing at these locations. Used clothing is deposited in containers at the local enclosures, and personnel check themselves for contamination prior to exiting the area. Personnel assigned to maintenance activities obtain their protective clothing in the locker room but don the clothing at the local work control point.

The Technical Support Building Break/Lunchroom also serves as the assembly area during emergency conditions. This area allows for the staffing of personnel for response teams. Space is provided to support assembly, briefings, and preparation for entry of multiple teams into the MFFF.

9.1.2.11 Savannah River Site Facilities

The MFFF may rely upon SRS for instrument calibration, medical support, and dosimetry issue.

9.1.2.12 Radiation Monitoring and Alarms

The radiation monitoring system is designed to monitor MFFF workspaces, through the use of general ARMs and airborne radiation monitors, to protect the health and safety of personnel. This design is accomplished by identifying occupancy requirements and their respective environments (i.e., considering the potential for elevated airborne radioactivity or changes to workspace radiation levels).

The MFFF radiation monitoring system consists of a number of different types of monitors: general ARMs (neutron and gamma) and airborne alpha contamination monitors. This combined monitoring system allows for the detection of the possible radiation that a worker may be exposed to during normal and abnormal operations. The system also provides trending information so that increasing radiation levels may be determined to facilitate removing the sources of radiation exposure or limiting the time that a worker might be in the general area.

In addition to individual monitoring devices carried by the workers, the digital radiation monitoring system monitors and tracks, for trending purposes, area background radiation levels. The CAMs, along with individual monitoring devices, take representative and timely measurements of radioactivity concentrations in air at workstations and general work areas to maintain worker exposures ALARA.

9.1.2.13 Area Radiation Monitoring

General area ARMs are provided to monitor the neutron or gamma radiation levels in rooms containing gloveboxes, production units, and the laboratory. ARMs are also placed where radiation workers are likely to be stationed or perform routine operations. These monitors detect and warn workers of an unexpected increase in the radiation level of the general area. Either a

neutron or gamma area monitor is provided, dependent on the primary source of radiation, to detect increases in radiation environments caused by significant variations in quantities of radioactive materials, including radiation from nearby gloveboxes and conveyors, loss or failure of shielding, or an unexpected source of direct radiation.

ARMs inform Health Physics and control room personnel of radiation levels in excess of the limit designated for an area (i.e., radiation zone limit) and/or a limit determined to be ALARA. Also, direct personnel monitoring may be performed through the use of worker alarming dosimeters.

Gamma and/or neutron ARMs are used, as deemed necessary, to monitor the intensity of radiation in areas where significant quantities of plutonium are stored and/or handled. Selected monitors have pre-selectable trip settings with audible annunciation, provide electronic signals for remote alarms, and/or are equipped with digital readout.

9.1.2.14 Airborne Radiation Monitoring

A person working in a glovebox (i.e., hands/arms extended into glovebox gloves) is required to have an airborne contamination monitoring device (i.e., CAM) located in close proximity to the breathing air zone. To ensure coverage at all glovebox workstations, the CAM sample heads are movable. These moveable heads contain the filter, detector, and electronics, connected to a combination wire and vacuum hose for communications and proper airflow for particulate collection. In addition to the CAMs provided for the numerous workstations, CAMs are also strategically placed in the routinely occupied areas surrounding the gloveboxes.

Most CAMs operate on the central vacuum system that provides a constant controlled airflow across the filter paper. The monitors draw a sample of the air from the vicinity of the worker onto a sample paper filter. An installed detector analyzes the filter paper and provides a signal to the local readout, and, readout and alarm monitors located in the Polishing Utilities Control Room and the Respirator Maintenance/Health Physics Room. The system also provides an alarm in the glovebox room, and in the airlocks for the glovebox room if the airborne contamination exceeds preset limits. Portable CAMs, with vacuum pumps, are available for use during maintenance and provide additional coverage as necessary.

To ensure that workers are provided adequate monitoring, there may be more than one CAM in a room. The actual number of CAMs is determined based on the anticipated number of operations and the potential for an uptake. Where there is a potential for airborne contamination, a monitor is installed so that the workers are provided coverage. The initial number and location of monitors are based on the MELOX and La Hague designs. Further evaluations will be conducted to determine the best locations for the MFFF CAMs. During maintenance activities, portable monitors will be installed as necessary, to provide additional monitoring of the task.

Airborne contamination monitors are installed to detect barrier failures. These monitors are placed in each room where personnel access is allowed and that contains the first confinement barrier. In rooms with no routine personnel access, airborne contamination monitors obtain air samples taken from the ventilation exhaust ducts exiting rooms (cells) as appropriate.

Alarm setpoints are provided at two distinct levels to enable the worker to take appropriate action if a release should occur. The lower (first) setpoint provides a warning of increasing airborne contamination so that the worker can exit the room or don appropriate respiratory equipment. This alarm also warns other workers outside the room that there is an increase in airborne contamination and that they should not enter the room without respiratory equipment. The alarm is provided with remote readouts in the Polishing Utilities Control Room and the Respirator Maintenance/Health Physics Room so that the process can be terminated and corrective actions can be initiated to stop the release.

The higher (second) alarm setpoint provides worker and remote readouts, indicating that personnel are in danger and that immediate actions are required to provide protective measures to the workers. These setpoints are less than the 10 CFR Part 20 Appendix B limits but above the warning level. In addition to local alarms, remote readouts and alarms are provided in the Polishing Utilities Control Room and the Respirator Maintenance/Health Physics Room.

During maintenance activities when a glovebox or a system boundary is opened, portable air samplers are used to monitor personnel inside contamination control enclosures. The use of portable monitors allows for closer supervision of the airborne activity in the area of the work. The portable units are provided with local and remote alarm capabilities to warn Health Physics and supervisory personnel, as well as the workers and personnel in the surrounding area.

A foot pedal is another design safety feature that further reduces the likelihood of airborne radioactivity uptake to the glovebox worker or others in the area. This device can be used by the glovebox worker to alert others of the need for help in case of a torn glove in the glovebox or other incident at the workstation. The foot pedal, placed near the glovebox operator, allows the operator to sound an audible and visual alarm in the Respirator Maintenance/Health Physics Room. The operator is trained to stay at the glovebox station, tell others in the area to stay clear, and wait for Health Physics support. Health Physics personnel immediately notify other workers in the general area and respond to support the glovebox worker.

9.1.3 Source Identification

9.1.3.1 Sources of Radiation and Contamination

Five primary radiation sources are used for radiation protection design: non-polished plutonium, polished plutonium, raffinates, master blend, and final blend. Non-polished plutonium, as received at the MFFF, contains daughter products from the original product that has decayed for about 40 years. As the facility nears the end of life, the original product received will have decayed about 70 years. These daughter products decay by beta and alpha emissions that are higher in abundance and energy than the original product material. Neutrons are produced by spontaneous fission and through alpha-neutron reactions. Impurities associated with input materials (see Chapter 11) are incorporated into the (α,n) reaction for the unpolished source.

Impurities from feed material originating from sources other than the PDCF have been analyzed to determine the impact on shielding design and estimated occupational doses. Impurities such as sodium and beryllium have an impact on the neutron intensities for feed material at the front

end of the AP process. This will have little impact on facility occupational doses since the operations in these cells are performed remotely.

Polished plutonium contains much less of the daughter products (or impurities from feed material originating from sources other than the PDCF), such that the radiation levels are lower. The master blend is a maximum of 20% PuO_2 with the balance being depleted UO_2. The final blend will be in the range of 2% to 6%. The conservative estimate for the long-term average for personnel exposure is assumed to be 5% PuO_2 + 95% depleted UO_2. Table 9-3 shows the non-polished plutonium source at 0 year decay, 40 year decay, and 70 year decay. Table 9-4 shows polished plutonium from AP, master blend, and final blend sources. Table 9-5 shows the AP raffinate sources.

The Radiological Isotopic Composition (RIC) is back-calculated using the decay schemes for the affected isotopes from Today's Isotopic Composition (TIC), which is based on 40 years of decay since the plutonium was first refined. The Final Isotopic Composition (FIC) is the decay of the TIC to a total of 70 years since the plutonium was first refined. The Raffinates Isotopic Composition (RAIC) corresponds to all of the mass of ^{241}Am obtained at the entrance of the AP Area; all of the daughters (except neptunium and thorium) produced by the decay of plutonium during 70 years; and a small amount of plutonium and uranium corresponding to the repartition of plutonium and uranium in the AP process. These notations are used in Tables 9-3 and 9-5.

Multiple sources are identified to maximize photon and neutron source terms. The 0-year decay sources represent the initial isotopic composition of the product material. The 40-year decay sources represent the expected isotopic compositions at the start of facility operations. The 70-year decay sources are the isotopic compositions at the maximum decay time expected at the facility. Non-routine and accident sources will be addressed in the license application for possession and use of SNM, as will additional details concerning shielding analyses (i.e., model and geometries).

A residual source of contamination is conservatively estimated for loss-of-confinement analysis and extremity dose analysis based on MELOX operating experience.

The occupational dose is assessed during the design phase. Significant occupational doses are evaluated for design enhancements to reduce the potential doses. ALARA evaluations are documented and summarized in the license application.

9.1.3.2 Source Pertinent Information

The sources identified in Section 9.1.3.1 are used to:

- Evaluate consequences in the safety assessment of the design basis
- Provide input to shielding codes used in the design
- Establish design features
- Develop plans and procedures
- Assess occupational dose.

9.1.3.3 MELOX and MFFF Source Term Comparison

The source term comparison in Table 9-6 is made to assist in extrapolating existing MELOX radiation exposure data to that for the MP Area. No source comparison is used for the AP process since the expected occupational exposure is small. In the absence of radiation dose rate and activity data at this time, existing MELOX data are extrapolated for the MFFF to estimate the expected occupational dose. These data provide a focus for design evaluations.

The specific activities associated with these sources are used in shielding calculations to determine the ratio of the dose rates for MELOX and the MFFF. In this way, the sources can be compared to extrapolate expected dose rates in the MFFF. Tables 9-7 and 9-8, along with Figures 9-10 and 9-11, provide comparisons of photon and neutron spectra, respectively.

The ratio of the MELOX photon dose to the MFFF photon dose is 20:1. This ratio is based on a calculated dose comparison for a specific geometry of the MELOX fuel (8.5%) to the final blend MFFF fuel (5%).

The ratio of the MELOX neutron dose to the MFFF neutron dose is 11:1. This ratio is based on the ratio of the intensities and on a comparison of the calculated dose rates for specific geometries from each facility.

9.1.4 Ventilation Systems and Glovebox Design

The design and operation of the ventilation system and gloveboxes are to protect workers from airborne radioactive material such that the limits of 10 CFR Part 20 are not exceeded during routine and non-routine operations and anticipated events.

The design objectives for the ventilation systems and gloveboxes ensure that during routine and non-routine operations and anticipated events, the airborne concentration in occupied operating areas will remain well below the limits of 10 CFR Part 20, Appendix B. Engineering controls are preferred over the use of respirators.

Uninterruptible power supplies (UPSs) ensure air monitoring and warning systems associated with the ventilation system and gloveboxes will function during a loss of power unless they can tolerate a temporary loss of function without loss of data. The air monitoring and warning systems are designed with a standby power supply.

Chapter 11 provides details of the system design for the ventilation system and gloveboxes.

9.1.4.1 Ventilation System Design

The ventilation system is designed to incorporate features that ensure workers are protected, to the greatest extent practical, from airborne radioactive material during normal and accident conditions. Many of the ventilation system design features described in this section also promote reduced airborne effluent releases and minimize exposures to site workers and members of the public.

The heating, ventilation, and air conditioning (HVAC) systems are designed to maintain negative pressure gradients between the building confinement zones and between the building and the outdoors to ensure that the airflow is from zones of lesser contamination potential to zones of greater contamination potential. The confinement systems are bounded by "confinement system boundaries," across which well-defined pressure gradients are maintained to ensure that any air exchange, and consequently airborne contaminants, through breaches is also from zones of lesser contamination potential to zones of greater contamination potential.

The system design provides for a progressively inward flow so that air flows from clean areas (C1 or C2 zones) to the most contaminated areas (C4 zones) (e.g., gloveboxes) and eventually exhausts via high-efficiency particulate air (HEPA) filters. C4 zones are the primary confinement zones containing process equipment and the associated cells and enclosures. C3 zones are broken down into two levels depending on the contamination hazard: C3a zones have a low occasional hazard, while C3b zones have a moderate hazard. C2 zones have a very low occasional contamination hazard, and C1 zones have no potential for contamination. Confinement zone maps are presented in Chapter 11.

Airlocks are provided at the access between zones of different depressurization levels and limited access areas where airflow must be maintained in one direction, from the lower to the higher potential contamination. The cascading air from the clean area through the airlock and into the potentially contaminated area minimizes the potential for airborne contaminant migration to the clean areas from the potentially contaminated areas during personnel access.

The very high depressurization exhaust system is designed to prevent any backflow due to "breaches" in static barriers to prevent the escape of airborne contaminants. To ensure that airflow is always away from workers and to ensure that radioactive materials remain inside the glovebox, a minimum of 125 linear feet per minute of airflow into the glovebox is maintained.

Monitors and alarms are provided to indicate changes in confinement pressures to warn personnel so that appropriate actions can be taken. The instrumentation for a glovebox or enclosure ventilation system includes devices to indicate the differential pressure between the glovebox or enclosure and the surrounding work area, the filter resistance, and the exhaust flow rate from the glovebox or enclosure. When glovebox or enclosure operations are not attended full time, a sensor is provided to monitor abnormal pressure and to alarm at a point where operations personnel are stationed.

The dynamic confinement systems are designed to operate continuously to protect personnel from exposure to airborne and transferable contamination. Redundancy ensures continuous operation of an HVAC system in the event of the failure of an active component (e.g., a fan or a damper) during normal or accident conditions.

Room airflow is designed to reduce the possibility of airborne radioactive materials being released in the vicinity of the worker's breathing zone during abnormal conditions. Air is supplied above the worker and exhausted as close to floor level as possible. This design provides for a "wash" across the worker, resulting in the air around the worker being maintained free of contaminants.

These design features minimize the potential that workers are exposed to airborne radioactive material during normal operations, maintenance, or accidents.

Airborne radioactivity monitoring and warning systems provided for worker protection and safety are powered by a reliable offsite power source. In the event offsite power is lost, the monitoring and warning systems are powered by standby power and UPS units. The monitoring and warning systems are connected to a data network, providing numerous communication links and readout capabilities. Alarms and instrument readouts are provided in the respective process area control rooms, the AP control room, and the Respirator Maintenance and Health Physics Room, which is used as the Operations Support Center during postulated events. The instrument readouts are also available in the Emergency Operations Center.

9.1.4.2 Glovebox System Design

The primary function of the glovebox is to protect workers from radioactive materials. The gloveboxes are considered the primary confinement and are designed to meet ALARA objectives for both direct and internal radiation sources and to ensure worker safety (see Chapter 11 for additional details concerning the glovebox design).

The glovebox design incorporates design techniques to minimize pockets and sharp corners. Smooth surfaces and rounded corners provide for ease of cleaning and recovery of material. This design reduces the localized collection of radioactive material and thereby reduces worker radiation exposures. Maintenance procedures address periodic cleaning inside the gloveboxes to remove dust and eliminate "hot spots" and contamination.

The gloveboxes are designed to withstand accidental conditions as defined by the safety assessment of the design basis (e.g., the design basis earthquake, over- or under-pressure). This design ensures that, in an accident condition, personnel are provided appropriate protection from a release of radioactive material. The glovebox design is based on providing adequate airflow and sealing surfaces to preclude releases from the glovebox. Glovebox penetrations are designed with glove ports that are sealed to prevent release of contamination.

9.1.5 Shielding Evaluations

MELOX operating experience is utilized throughout the MFFF design process to minimize occupational and public radiation exposures. Actual operating experience that defines the occupancy for each of the process units is used to estimate the occupational exposures for each glovebox. Radiation sources are determined for the MFFF. The redesign of some process units for process reasons and/or to optimize radiation protection will be taken into account in the analysis. These sources are used to calculate the dose rates and thus establish the radiation shielding requirements. Process units that result in higher occupational exposure are reviewed to maximize productivity, minimize maintenance, and thus minimize radiation exposures. The types of MELOX data used for the MFFF design are as follows:

- Personnel access requirements:
  - Description of activities
  - Proximity to radiation sources

- Definition of radiation sources
- Duration of activities
- Duration of time that hands are in the gloveboxes.

- Radiation exposure data:
  - Total facility doses
  - Doses for each process zone (i.e., powder, pellets, rods, and assemblies)
  - Doses from routine operations
  - Gamma versus neutron dose rates.

Permanent shielding is designed in the facility to lower dose rates to comply with 10 CFR Part 20 during routine and non-routine operations and anticipated events. DCS has developed radiation zone drawings that contain higher radiation zones within decreasing lower radiation zones (see Section 9.1.2.3.1). The design will identify and describe areas in which temporary shielding will be required for non-routine maintenance. Provisions will be incorporated into the design to minimize the time required to install temporary shielding by designing the type of temporary shielding anticipated and by designing temporary shielding storage locations.

Design goals for internal and direct doses will be based on fractions of 10 CFR Part 20 limits. These are developed in the design by making use of the design features and experience of the MELOX and La Hague facilities. The use of actual exposure data and the difference in the source terms between MELOX and MFFF material facilitate setting these design goals. The permanent and temporary shielding developed as part of this design meets these design goals. The design goals are set based on this dose estimate.

The TEDE design goal (i.e., ALARA and minimize the number of operators with occupational doses greater than 500 mrem/yr) is established early in the design process for individual workers and is also intended to be applied to the facility operations.

Detailed design drawings and descriptions of the shielding for high and very high radiation areas are developed to clearly identify the penetrations, shield doors, and labyrinths incorporated to meet the design shielding criteria. Radiation shielding analyses are used to verify the shielding for each process room including the dose rates for each position workers are required to take to perform routine and non-routine maintenance. This design is based on experience and the design features of the MELOX facility. Details of the shielding design and the dose estimate will be provided in the Integrated Safety Assessment (ISA) Summary with the license application for possession and use of SNM.

A Radiation Shielding Test Program will verify the efficacy of the installed shielding materials in meeting the radiation shielding design goals and the regulatory direct dose requirements of 10 CFR Part 20.

Several standard industry computer codes are used in the shielding calculations (e.g., Monte Carlo N-Particle [MCNP], SCALE, Perceval, SN1D, Microshield). The computer codes are discussed in Section 9.1.5.4.

The shielding design complies with 10 CFR §20.1406 requirements for the minimization of contamination and uses the MELOX facility design experience for guidance. The MFFF facilitates waste minimization of shielding materials. The design includes permanent shielding in the process rooms. Temporary shielding that could add to radioactive waste volumes will be minimized based on the uses described previously in this section.

The Project Quality Assurance Program applies to the shielding design. This program will be used as appropriate in shielding design, procurement, installation, maintenance, and operation.

9.1.5.1 Shielding Information for Each Radiation Source

Shielding information for each radiation source will be provided in the license application for possession and use of SNM.

9.1.5.2 Criteria for Penetrations

Penetrations in shielding for high radiation sources are minimized in the design. For lower dose rate sources, the impacts are analyzed in shielding analyses. Penetration analyses will be discussed further in the license application for possession and use of SNM.

9.1.5.3 Shielding Materials

Standard shielding materials are used to attenuate the radiation intensity at the worker. Materials such as leaded glass, leaded polymers, borated concrete, borated polymers, borated plasters, and ordinary concrete are utilized. ANSI/ANS-6.4.2-1985, R1997 is used as the reference for shielding material properties for performing calculations.

9.1.5.4 Computer Codes

The MCNP computer code is used to estimate photon and neutron transport. Source configurations (e.g., jars of powder, vessels of liquids, trays of pellets, rods, and assemblies) are modeled in the computer software to estimate direct and scattered radiation.

The MicroShield computer code is used to check the photon shielding analyses of gloveboxes.

The SCALE computer code was designed by the Radiation Shielding Information Computational Center at Oak Ridge National Laboratory for the NRC. It is comprised of several control modules that perform specific analysis tasks. The control module SAS1 is used for a one-dimensional neutron dose rate analysis for this project. SAS1 uses functional modules BONAMI, NITAWL-II, and XSDRNPM to process cross sections, XSDRNPM to perform the shielding calculation, and XSDOSE to calculate dose rates.

The Perceval and SN1D codes are used by Cogema in France. Perceval is a nuclear radiation protection software program that calculates the gamma dose equivalent rate or the radiation shielding thickness for a given gamma dose equivalent rate. SN1D is a discrete ordinates code. The SN1D calculation system is used for solving the Boltzmann neutral neutron and gamma particles transport equation. The one-dimensional computer code accepts plane, spherical, and cylindrical geometries. The multigroup approach allows the calculation of a particle flow within

each energy group; the possible boundary conditions are the vacuum, reflection, and albedo conditions. It can handle the scattering and external source anisotropy, making a direct or subsidiary calculation. The reaction rates and dose rates are assessed from the flows.

Neutron sources are adjusted for subcritical multiplication and alpha-neutron reactions. Photon sources include daughter products of plutonium decay that contribute to the photon source term over the facility's lifetime.

Each source of radiation within the facility is identified and included in the shielding analysis to estimate radiation dose rate fields throughout the facility. Shielding materials are selected for the source term to effectively reduce dose rates to meet ALARA goals. Borated polymers are used for neutron attenuation, and leaded plastic and glass are used for photon shielding in the glovebox units. AP areas contain stainless steel vessels with concrete shielding between equipment. Dose collection points (or tallies or detector points) are set at locations of expected occupancy. Multiple dose collection points are chosen to represent the position of the whole body and the extremities. ANSI 6.1.1-1977 flux-to-dose conversion factors are used to estimate dose rates.

9.1.5.5 Special Protective Features

Special features to ensure that normally occupied areas are ALARA (as applicable) will be defined during final design and summarized with the license application for possession and use of SNM.

9.1.6 Integrated Safety Analysis

Chapter 5 describes the programmatic and analytical details of radiation safety associated with design basis events (i.e., the safety assessment of the design bases of principal SSCs). The ISA Summary will be completed and submitted with the license application for possession and use of SNM.

9.2 RADIATION PROTECTION PROGRAM

The Radiation Protection Program specifically implements the requirements of 10 CFR Part 20, *Standards for Protection Against Radiation*, and the appropriate sections of 10 CFR Part 19, *Notices, Instructions and Reports to Workers: Inspection and Investigations*, and 10 CFR Part 70, *Domestic Licensing of Special Nuclear Material*. The Radiation Protection Program implements the necessary programmatic requirements to ensure that radiological work activities are performed in a manner that protects the health and safety of workers.

9.2.1 Radiation Protection Program Description

The Radiation Protection Program ensures the following:

- The individual worker's exposure to radiological hazards is ALARA.
- Personnel responsible for performing radiological work are appropriately trained.

- Personnel responsible for implementing and overseeing the Radiation Protection Program are technically competent.
- The ALARA process is incorporated into the facility design, modifications, and work processes.
- Line management is involved and accountable for radiological performance.
- Radiological measurements, analyses, worker monitoring results, and estimates of public exposures are accurately and appropriately conducted.
- Radiological operations are conducted in a manner that controls the spread of radioactive materials and reduces exposure to the workforce and the general public, and a process is utilized that maintains exposure levels ALARA.

Radiological facilities and areas will be operated in such a manner to meet radiological dose limits and to meet the goals of the ALARA Program and Regulatory Guide 8.10, *Operating Philosophy for Maintaining Occupational Radiation Exposures As Low As Is Reasonably Achievable*. Radiological work activities performed under this materials license, including those performed by subcontractors, will meet the requirements of the Radiation Protection Program.

Operating plans and procedures will be developed in consideration of ALARA principles. The following considerations will be included for operations:

- Training is provided to operations personnel to minimize the potential for plutonium inhalation.
- Preventive maintenance is performed during times when no sources are being processed, or alternatively, maintenance is performed on equipment outside radiation areas.
- Dry runs are performed during startup testing to determine probable radiation exposures, and results are factored into operating procedures.
- Pre-operational and continuing training on procedures, including dry runs, is conducted for operations personnel to minimize radiation exposures.
- Contingency procedures are developed for off-normal occurrences and accidents, including recovery operations.

9.2.2 Radiation Protection Program Functional Elements

9.2.2.1 ALARA Program

9.2.2.1.1 ALARA Program Description

The ALARA policy is to keep radiation exposures within regulatory limits and to ensure that radiation exposure is ALARA. Line management and the workforce are committed to this policy. The ALARA Program is composed of the following:

- ALARA Program description and procedures
- ALARA Committee

- ALARA Chairman
- ALARA Program Coordinator – A member of the Radiological Protection staff will be appointed as the ALARA Program Coordinator, who will assist the ALARA Chairman in implementing the ALARA Program.

9.2.2.1.2 Management Commitment

The responsibility for complying with radiological protection requirements and for maintaining radiation exposures ALARA starts with the individual worker and broadens as it progresses upward through the organization. Line managers are fully responsible for radiological performance among their personnel and take necessary actions to ensure that personnel are properly trained and that performance to the requirements is monitored and corrected as necessary. As part of the commitment to the Radiation Protection Program, senior management ensures that the ALARA Program is implemented and that line management is held accountable.

9.2.2.1.3 ALARA Committee

The ALARA Committee provides the focus and direction for improving the Radiation Protection Program. The ALARA Committee includes the ALARA Chairman (who is a member of line management and nominated by senior management); the ALARA Program Coordinator; the Radiological Protection Manager; and personnel from line management, operations, and the technical support organizations. Radiological protection personnel act as advisors to the committee.

9.2.2.1.4 Administrative Control Levels and Dose Limits

The objective of minimizing radiation exposure is to maintain individual radiation doses ALARA, but in all cases below regulatory limits. To accomplish this objective, administrative control levels are established below the regulatory limits to control individual and collective radiation dose. The administrative control levels are multi-tiered with increasing levels of authority required to exceed higher administrative control levels. Unless otherwise indicated, administrative control levels and dose limits are stated in terms of the total effective dose equivalent (TEDE).

9.2.2.1.5 Internal Audits and Assessments

Internal self-assessments by radiation protection and plant operating/maintenance personnel are routinely performed to provide continuous evaluation of the Radiation Protection Program for needed procedural and implementation improvements. Formal independent audits performed by the quality assurance organization will also be scheduled and performed such that over a 12-month period, functional elements of the Radiation Protection Program are evaluated for program compliance and implementation. These audit results provide valuable feedback to line managers on those areas that need more management attention.

9.2.2.2 Organization and Administration

9.2.2.2.1 Radiological Protection Organization

During operations, the radiological protection organization is independent of the operations and maintenance organizations. The radiological protection organization provides relevant support to facility operations. The radiological protection organization develops policies and procedures to ensure compliance with 10 CFR Part 20. Written procedures are developed and implemented as necessary to ensure compliance with 10 CFR §20.1101(b).

Individuals responsible for developing and implementing measures necessary for ensuring compliance with the requirements of 10 CFR Part 20 have the appropriate education, training, and skills to discharge these responsibilities. The radiological protection organization, working with facility management, ensures adherence to the Radiation Protection Program in operations and provides the required radiological support to the facility organization.

9.2.2.2.2 Radiological Protection Manager

The Radiological Protection Manager is responsible for setting radiological protection policy and has direct access to senior-level management for implementation of this policy. In addition, the Radiological Protection Manager has the responsibility for planning, administering, and maintaining the Radiation Protection Program with support from line management at all levels. The Radiological Protection Manager will ensure that the Radiation Protection Program elements are appropriately implemented and maintained through radiological policies, procedures, and documents. The Radiological Protection Manager, or his designee, will approve radiological protection policies and procedures.

9.2.2.3 Radiation Safety Procedures and Radiation Work Permits

The primary methods used to control workplace exposure are operating procedures and facility and equipment design features. These controls are augmented with the use of area entry/exit requirements to control access to and from radiological areas and RWPs to control radiological work. Proposed maintenance and modification plans are reviewed to identify and incorporate radiological protection requirements.

Employees have the authority and responsibility to stop radiological work activities suspected of being unsafe.

9.2.2.3.1 Radiological Work Planning

Performance of work planning is the responsibility of line management, with support from the radiological protection organization. Radiological surveys are used to develop the radiological protection requirements and are documented on the RWP. Specific radiological controls based on the surveys, and from any formal ALARA reviews that were performed because established planning thresholds were exceeded, are incorporated into the work documents. Line management ensures that safety requirements supplement each other and do not conflict for the overall safety of the worker.

9.2.2.3.2 Entry and Exit Control

Specific requirements for entering and exiting radiological areas are established. Radiation safety training commensurate with the hazards and required controls is required before unescorted access to radiological areas is permitted. The primary control for entry into radiological areas is the RWP, which is augmented by signs and barricades. For access to high and very high radiation areas, the process meets the requirements of 10 CFR §20.1601 and §20.1602 and employs one or more control devices, which include conspicuous visual and/or audible alarms, locked entrances, and/or administrative controls.

9.2.2.3.3 Radiological Work Controls

Positive control of personnel is established through RWPs, and the dose and training status of each employee entering radiological controlled areas are confirmed prior to entry. Only trained and qualified personnel, who have the information available to understand and respond to the radiological conditions that they will encounter during the work activity, are allowed to enter the restricted area unescorted. In some circumstances, specialists may be granted escorted access to perform specific tasks with permission of the Radiological Protection Manager.

The RWP is the administrative mechanism used to establish radiological controls for intended work activities. The RWP informs employees of area radiological conditions and entry requirements and provides a mechanism to relate employee exposure to specific work activities.

9.2.2.3.4 Posting and Labeling

Posting and labeling of radiation areas and radiologically contaminated areas, equipment, and material are used to alert personnel about the radiological status of the item or area and to prevent any inadvertent dose to the worker. This program includes the use of the standard radiological posting and labeling and meets the requirements of 10 CFR Part 20 Subpart J. The program also controls posting of signs so they are clearly and conspicuously posted.

9.2.2.3.5 Release of Materials and Equipment

Material and equipment that are contaminated or potentially contaminated are considered contaminated until they are surveyed and released. This program is implemented to ensure that no contaminated material or equipment is released from the control of the program. The program controls the movement of material and equipment from contamination areas and between controlled areas. The program also controls the release of material and equipment from controlled areas and from the site.

9.2.2.3.6 Sealed Radioactive Source Accountability and Control Program

The purpose of this program is to control radioactive sealed sources and to prevent the loss or unintentional exposure of the worker to these sources. The program sets the accountability requirements for sources and monitoring requirements.

9.2.2.3.7 Receipt of Packages Containing Radioactive Material

The Transportation Program controls the receipt of packages containing radioactive materials. The purpose of this program is to ensure that appropriate controls are implemented for these packages from the time of receipt to its final destination. This program will prevent any unauthorized access to the packages and ensure that any subsequent radiation dose will be maintained ALARA.

9.2.2.4 Radiation Safety Training

Radiation safety training is commensurate with the employee's duties. Standardized core courses are utilized, to the extent practicable, and are supplemented by facility-specific information. Depending on their work activities, employees will take General Employee Training or Radiological Worker Training (see Section 1.1.2.1).

9.2.2.5 Air Sampling

The Airborne Radioactivity Monitoring Program uses air samplers and/or CAMs, and usage is based on the working conditions. The program is designed to minimize the internal exposure to the radiation workers and is part of the overall ALARA Program. The estimation of internal dose will be based upon airborne radioactivity concentrations. In the event of high exposures, the internal dose will be verified by also using bioassay data.

9.2.2.6 Contamination Monitoring and Control Program

The Contamination Monitoring and Control Program is designed to prevent the movement of radioactive contamination from controlled areas to uncontrolled areas and to monitor personnel and equipment leaving contamination areas. Radioactive contamination is controlled by using engineering controls, by containing contamination at the source, by monitoring, and by promptly decontaminating areas that become unintentionally contaminated.

The program requires surveying of contamination areas to determine the current levels of contamination. The survey results are also used to determine if postings are correct and if additional controls are required and to determine the appropriate personnel protective equipment.

9.2.2.7 Direct Exposure Control Program

The Direct Exposure Control Program provides the following:

- Exposure monitoring
- Dosimeters and their processing
- Dose determinations
- Dose record maintenance
- Dose reporting
- Records maintenance.

Dosimetry will be processed and evaluated by a processor accredited by the National Voluntary Laboratory Accreditation Program. The purpose of the Direct Exposure Control Program is to

ensure that radiation workers' doses do not exceed dose limits. The program is composed of the following:

- The measurement of the direct radiation dose received by workers using a dosimeter
- Control, as practicable, of personnel that have received radiopharmaceuticals
- Planned special exposures
- Exposure limit for minors and the general public
- Radiological protection for the embryo/fetus.

9.2.2.8 Internal Exposure Control Program

The Internal Exposure Control Program identifies both the discretionary and non-discretionary bioassay sampling requirements and is designed to monitor internal uptakes and to determine the quantity of the uptake. The program is composed of the following:

- The non-discretionary measurement of the internal radiation dose received by workers who are likely to receive a committed effective dose equivalent (CEDE) to the whole body of greater than 500 mrem in a year
- The discretionary measurement of workers to determine the effectiveness of the Respiratory Protection Program.

9.2.2.9 Summing of Internal and Direct Exposure

Doses will be summed using the guidance provided in Regulatory Guide 8.7, *Instructions for Recording and Reporting Occupational Radiation Exposure Data*; Regulatory Guide 8.34, *Monitoring Criteria and Methods to Calculate Occupational Radiation Doses*; and Regulatory Guide 8.36, *Radiation Dose to the Embryo/Fetus.*

The maximum doses allowed for occupationally exposed workers are contained in 10 CFR §20.1201. These limits apply to all radiation workers 18 years of age or older. These limits are expressed in units of dose equivalent (DE) in rem and Sv. Internal dose to a specific organ is given as committed dose equivalent (CDE), while the internal dose relative to a whole-body exposure is given as CEDE. Direct dose is expressed as deep dose equivalent (DDE), shallow dose equivalent (SDE), and lens of the eye dose equivalent (LDE).

The annual occupational exposure limits from 10 CFR Part 20 are as follows:

- Total (CEDE + DDE) = TEDE 5 rem (0.05 Sv)
- Lens of Eye (LDE) 15 rem (0.15 Sv)
- Other Organs (CDE + DDE) 50 rem (0.5 Sv)
- Skin or Extremity (SDE) 50 rem (0.5 Sv).

Note: The extremities are considered to be the hand, elbow, arm below the elbow, foot, knee, and leg below the knee.

9.2.2.10 Respiratory Program

Using ALARA concepts, the use of respiratory protection is minimized and will be determined to ensure that the TEDE dose is optimized for the work activity. Specialized training and a medical evaluation are required for individuals required to wear respirators. The Respiratory Program will follow the guidance of ANSI-Z88.2-1992, *Practices for Respiratory Protection*, ANSI-Z88.6-1984, *Physical Qualifications for Respirator Use*, and NUREG-0041, *Manual of Respiratory Protection Against Airborne Radioactive Materials.*

9.2.2.11 Instrument Calibration and Maintenance Program

The Instrument Calibration and Maintenance Program ensures that the fixed and portable radiological protection instrumentation used for the Radiation Protection Program are appropriately calibrated and maintained in accordance with ANSI 323. This program ensures that the instruments used in the Radiation Protection Program produce accurate and reproducible results.

9.2.2.12 Area Monitoring and Control

In general, the workplace is monitored to:

- Document radiological conditions in the workplace
- Detect changes in radiological conditions
- Detect the gradual buildup of radioactive material in the workplace
- Verify the effectiveness of engineering and process controls in containing radioactive material and in reducing radiation exposure
- Determine the level of posting that is required
- Determine the appropriate dosimetry, personnel protective clothing, and respiratory requirements on the RWP
- Demonstrate compliance with the requirements of the Radiation Protection Program.

9.2.2.13 Records

Complete and accurate radiation protection records of the facilities, including the records of individuals who work in or visit them, are maintained in accordance with 10 CFR Part 20 Subpart L. Reports are formatted in accordance with 10 CFR §20.2110. These records are used to document the radiation exposures of individuals and are available as prescribed by the Privacy Act of 1974. These records are also used for (1) evaluation of the effectiveness of the Radiation Protection Program, (2) demonstration of compliance with regulations and requirements, and (3) personnel records. These dose records are sufficient to evaluate compliance with applicable dose limits and monitoring and reporting requirements.

9.2.2.14 Reports to Individuals

As a minimum, exposure reports are provided to individuals under the following conditions:

- Upon request from an individual terminating employment, records of exposure are provided to that individual when the data become available.
- If requested, a written estimate of radiation dose, based on available information at the time of termination, is provided.
- Annual radiation dose reports are provided to individuals monitored during the year.
- If requested, detailed exposure information is provided.
- Reports are provided to individuals when required to report to the NRC pursuant to occurrence reporting and processing, or planned special exposures.

9.3 DESIGN BASIS FOR RADIATION PROTECTION

This section discusses the design bases requirements applicable to systems, equipment, and design features associated with radiation protection. Principal SSC concepts are described in Chapter 5. The systems, equipment, and other radiation protection design features discussed below are not principal SSCs.

The MFFF basis of design for radiation protection is to ensure that SSCs necessary to maintain the safety and health of the workforce are in compliance with the requirements of 10 CFR Part 70 and 10 CFR Part 20. The MFFF is designed to provide radiation protection for workers in conformance with applicable regulatory criteria so that occupational radiation exposures are maintained ALARA. Guidance provided by NRC Regulatory Guides, DOE Program Implementation Guides and Standards, and various industry codes and standards is used.

The ARMs, CAMs, PCMs, other radiation monitoring equipment, and temporary and permanent radiation protection features are designed to monitor direct radiation and potential airborne or surface radioactive contaminants, for the purpose of protecting the health and safety of workforce personnel.

The systems, equipment, and radiation protection design features are designed using the following documents:

- 10 CFR Part 20, *Standards for Protection Against Radiation*
- 10 CFR Part 70, *Domestic Licensing of Special Nuclear Material*, including proposed draft rule text dated July 30, 1999
- Regulatory Guide 8.8 (1978), *Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Reasonably Achievable*
- Regulatory Guide 8.10 (1977), *Operating Philosophy for Maintaining Occupational Radiation Exposures As Low As Is Reasonably Achievable*
- Regulatory Guide 8.25 (1992), *Air Sampling in the Workplace*
- ANSI/ANS-6.1-1-1977, *Neutron and Gamma-Ray Flux-to-Dose Rate Factors*

- ANSI/ANS-6.4-1977, *Guidelines on the Nuclear Analysis and Design of Concrete Radiation Shielding for Nuclear Power Plants*
- ANSI/ANS-6.4.2 (1985, R1997), *Specification for Radiation Shielding Materials*
- ANSI-N13.1-1969, *Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities* [Reaffirmed 1993]
- NUREG/CR-0446, *Determining Effectiveness of ALARA Design and Operational Features*, April 1979
- DOE-STD-1128-98, *Guide of Good Practices for Occupational Radiological Protection in Plutonium Facilities.*

The MFFF design reflects consideration of ALARA principles given in NRC Regulatory Guide 8.8. Specific ALARA considerations in the MFFF design include the following:

- Multiple confinement barriers to prevent contamination spread
- Remotely operated equipment and remote readout of instrumentation to minimize personnel access to radiation areas
- Use of permanent shielding designed to minimize personnel exposure
- Use of moveable radiation shielding to minimize radiation streaming
- Access restrictions for radiation areas featuring a minimum of access points to easily control personnel ingress.

To minimize the potential for internal occupational exposures, a secondary confinement system comprises at least one confinement barrier and is provided where the potential for breach exists in primary confinement during normal operations or in an incident or accident situation.

The design of the facility ensures that the TEDE to individual members of the public from the MFFF will not exceed 100 mrem in a year from normal operations and anticipated operational occurrences. The design also ensures that annual occupational doses are maintained below a TEDE of 5 rem and 50 rem to any extremity.

The TEDE design goal for individual workers will be ALARA and less than 500 mrem/yr to most of the operating team members, with an extremity exposure goal of less than 10 rem/yr.

Worker training is provided that identifies potential loss of confinement events. Instructions on the quick identification of the event and worker response are provided.

To detect and warn workers of unexpected increases in direct radiation and airborne radioactivity concentrations, ARMs and CAMs are placed in general workspaces. As necessary, gamma and/or neutron ARMs are used to monitor the intensity of radiation in areas where significant quantities of plutonium are stored and/or handled. CAMs are installed where personnel without respiratory protection could receive an annual intake of 2% or more of the specified annual limit

on intake (ALI) values (i.e., 40 Derived Air Concentration [DAC] hours). To detect a barrier failure as close to the source of leakage as possible and minimize the potential for undetected uptake of airborne radioactivity, CAMs are placed at specified glovebox workstations based on risk.

The MFFF CAMs, including sample points and sample lines, are designed to reach the lowest detection level possible (i.e., approaching less than or equal to 4 DAC-hr concentrations of ^{238}Pu). Additionally, sample lines are eliminated when practical, and when not practical, are designed with short lines, proper sampling rate, and smooth bends.

Airborne radioactivity in the AP cells will be monitored by taking representative samples of the exhaust air in the ventilation duct. This same approach will be used to monitor the air from selected high-risk MFFF processing areas.

PCMs are permanently installed at the exit of the AP and MP process areas to ensure that workers are not contaminated when they leave the radiation areas. ARMs, CAMs, and PCMs receive normal electrical power from a reliable source and, following the loss of offsite power, the monitors are powered by UPS and standby diesel power sources. Hand survey instruments and laboratory equipment are provided and strategically located to perform routine and non-routine radiation surveys of direct radiation, airborne radioactivity, and surface contamination in the AP and MP Areas and general MFFF spaces.

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Tables

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Table 9-1. MFFF Radiation Zoning Criteria

Radiation Zone	Design Basis Maximum Area Radiation Dose Rate (mrem/hr)
1 - High access, Non-radiation area	<0.05
2 - Intermediate access, Radiation area	<0.25
3 - Low access, Radiation area	<5.0
4 - Very low access, High radiation area	<100
5 - No access, Very high radiation area	>100

Table 9-2. MELOX Event INES Ratings

Event Date	Unit	INES Rating
03/16/95	Powder	Level 0
06/25/96	Powder	Level 0
08/17/96	Pellet	Level 0
08/07/97	All Ventilation	Level 1
01/09/98	Pellet	Level 0
09/26/98	Pellet	Level 0
02/08/99	UO_2 Powder	Level 0
06/29/99	Laboratory	Level 0
11/03/99	UO_2 Powder	Level 0
11/14/00	Pellet	Level 1
12/09/01	Pellet	Level 0
01/14/02	Pellet	Level 0

INES – International Nuclear Event Scale
Data are current as of August 2002

Table 9-3. Non-Polished Plutonium Sources

Non-Polished Plutonium Sources			
Isotope	Concentration (gm/gm Pu+Am)		
	0 yr RIC	40 yr TIC	70 yr FIC
He-4		2.52E-05	5.27E-05
Tl-207		1.59E-21	5.11E-20
Tl-208		1.87E-17	1.40E-17
Tl-209			1.05E-24
Pb-206		1.06E-15	1.47E-14
Pb-207		1.28E-15	4.65E-14
Pb-208		2.76E-10	4.37E-10
Pb-209			4.38E-21
Pb-210		4.18E-15	3.21E-14
Pb-211		1.23E-20	3.95E-19
Pb-212		1.10E-14	8.26E-15
Pb-214		3.89E-20	1.97E-19
Bi-209			5.76E-17
Bi-210		2.57E-18	1.97E-17
Bi-211		7.24E-22	2.33E-20
Bi-212		1.05E-15	7.83E-16
Bi-213			1.03E-21
Bi-214		2.89E-20	1.46E-19
Po-210		7.11E-17	5.45E-16
Po-211		8.88E-27	2.86E-25
Po-212		5.53E-26	4.14E-26
Po-213			1.54E-30
Po-214		3.98E-27	2.01E-26
Po-215		1.03E-26	3.31E-25
Po-216		4.40E-20	3.30E-20
Po-218		4.51E-21	2.28E-20
At-217			1.24E-26
Rn-219		2.33E-23	7.50E-22
Rn-220		1.66E-17	1.24E-17
Rn-222		8.30E-18	4.19E-17
Fr-221			1.12E-22
Fr-223		1.08E-22	3.48E-21
Ra-223		5.92E-18	1.90E-16
Ra-224		9.61E-14	7.20E-14
Ra-225			5.07E-19
Ra-226		1.29E-12	6.52E-12
Ra-228		4.43E-20	1.64E-19
Ac-225			3.43E-19
Ac-227		4.19E-15	1.35E-13
Ac-228		4.63E-24	1.71E-23
Th-227		9.72E-18	3.13E-16
Th-228		1.87E-11	1.40E-11
Th-229			9.35E-14
Th-230		1.07E-08	3.05E-08

Table 9-3. Non-Polished Plutonium Sources (continued)

Non-Polished Plutonium Sources			
Isotope	Concentration (gm/gm Pu+Am)		
	0 yr RIC	40 yr TIC	70 yr FIC
Th-231		4.24E-15	7.74E-14
Th-232		1.50E-10	4.58E-10
Th-234		1.02E-18	1.83E-14
Pa-231		2.02E-11	5.62E-10
Pa-233			1.84E-11
Pa-234m		3.45E-23	6.16E-19
Pa-234		1.54E-23	2.75E-19
U-232		6.96E-10	5.22E-10
U-233			2.33E-09
U-234		1.83E-04	2.86E-04
U-235		1.83E-02	1.90E-02
U-236		2.57E-04	4.49E-04
U-237			7.31E-11
U-238		1.26E-03	1.26E-03
Np-237			5.42E-04
Pu-236	1.00E-09	5.98E-14	4.06E-17
Pu-238	6.86E-04	5.00E-04	3.95E-04
Pu-239	9.21E-01	9.20E-01	9.19E-01
Pu-240	6.18E-02	6.15E-02	6.13E-02
Pu-241	1.00E-02	1.00E-02	1.00E-02
Pu-242	1.00E-03	1.00E-03	1.00E-03
Am-241		7.00E-03	7.92E-03

RIC – Radiological Isotopic Composition

TIC – Today's Isotopic Composition

FIC – Final Isotopic Composition

Table 9-4. Polished Plutonium Sources

Isotope	Concentration at t=70 yrs		
	Polished Pu From AP (gm/gm Pu + U+Np+Th)	Master Blend (20%) (gm/gm Pu+U+Np+Th)	Final Blend (5%) (gm/gm Pu+U+Np +Th)
Th-227	3.13E-17	6.31E-18	1.58E-18
Th-228	1.40E-12	2.82E-13	7.06E-14
Th-229	9.35E-15	1.89E-15	4.71E-16
Th-230	3.05E-09	6.15E-10	1.54E-10
Th-231	7.74E-15	1.56E-15	3.90E-16
Th-232	4.58E-11	9.23E-12	2.31E-12
Th-234	1.83E-15	3.69E-16	9.21E-17
U-235		2.00E-03	2.38E-03
U-238		7.98E-01	9.48E-01
Np-237	1.09E-04	2.19E-05	5.47E-06
Pu-236	4.06E-17	8.19E-18	2.05E-18
Pu-238	3.95E-04	7.95E-05	1.99E-05
Pu-239	9.19E-01	1.85E-01	4.63E-02
Pu-240	6.13E-02	1.24E-02	3.09E-03
Pu-241	1.00E-02	2.02E-03	5.04E-04
Pu-242	1.00E-03	2.02E-04	5.04E-05

Table 9-5. AP Raffinate Sources

Raffinate Source Constituents	
Isotope	Concentration (gm/gm Pu + Am) RAIC at 70 yr
He-4	5.27E-05
Tl-207	5.11E-20
Tl-208	1.40E-17
Tl-209	1.05E-24
Pb-206	1.47E-14
Pb-207	4.65E-14
Pb-208	4.37E-10
Pb-209	4.38E-21
Pb-210	3.21E-14
Pb-211	3.95E-19
Pb-212	8.26E-15
Pb-214	1.97E-19
Bi-209	5.76E-17
Bi-210	1.97E-17
Bi-211	2.33E-20
Bi-212	7.83E-16
Bi-213	1.03E-21
Bi-214	1.46E-19
Po-210	5.45E-16
Po-211	2.86E-25
Po-212	4.14E-26
Po-213	1.54E-30
Po-214	2.01E-26
Po-215	3.31E-25
Po-216	3.30E-20
Po-218	2.28E-20
At-217	1.24E-26
Rn-219	7.50E-22
Rn-220	1.24E-17
Rn-222	4.19E-17
Fr-221	1.12E-22
Fr-223	3.48E-21
Ra-223	1.90E-16
Ra-224	7.20E-14
Ra-225	5.07E-19
Ra-226	6.52E-12
Ra-228	1.64E-19
Ac-225	3.43E-19
Ac-227	1.35E-13
Ac-228	1.71E-23
Pa-231	5.62E-10
Pa-233	1.84E-11
Pa-234m	6.16E-19
Pa-234	2.75E-19
U-232	7.97E-13

Table 9-5. AP Raffinate Sources (continued)

Raffinate Source Constituents	
Isotope	Concentration (gm/gm Pu + Am) RAIC at 70 yr
U-233	3.55E-12
U-234	4.38E-07
U-235	2.91E-05
U-236	6.86E-07
U-237	1.12E-13
U-238	1.92E-06
Pu-236	1.32E-21
Pu-238	1.28E-08
Pu-239	2.98E-05
Pu-240	1.99E-06
Pu-241	3.24E-07
Pu-242	3.24E-08
Am-241	7.92E-03

RAIC – Raffinates Isotopic Composition

Table 9-6. Radionuclide Inventory Comparison

Isotope	MELOX (% per gram of metal)		MFFF (% per gram of metal)	
	30% PuO_2	8.5% PuO_2	20% PuO_2	5% PuO_2
Ru-106	6.24E-10	2.58E-10		
Rh-106	5.81E-16	2.41E-16		
Tl-208	2.17E-14	7.61E-15		
Bi-212	1.21E-12	4.26E-13		
Th-227			6.31E-16	1.58E-16
Th-228			2.82E-11	7.06E-12
Th-229			1.89E-13	4.71E-14
Th-230			6.15E-08	1.54E-08
Th-231			1.56E-13	3.90E-14
Th-232			9.23E-10	2.31E-10
Th-234			3.69E-14	9.21E-15
Np-237			2.19E-03	5.47E-04
U-232	1.15E-06	3.86E-07		
U-233	9.26E-08	1.21E-07		
U-234	3.41E-02	2.35E-02		
U-235	6.63E-01	8.64E-01	2.00E-01	2.38E-01
U-236	2.89E-01	3.71E-01		
U-237	7.38E-08	2.09E-08		
U-238	6.08E+1	7.94E+01	7.98E+01	9.48E+01
Pu-236	3.48E-07	9.86E-08	8.19E-16	2.05E-16
Pu-238	4.56E-01	1.29E-01	7.95E-03	1.99E-03
Pu-239	1.54E+01	4.37E+00	1.85E+01	4.63E+00
Pu-240	6.01E+00	1.71E+00	1.24E+00	3.09E-01
Pu-241	2.43E+00	6.89E-01	2.02E-01	5.04E-02
Pu-242	1.33E+00	3.77E-01	2.02E-02	5.04E-03
Am-241	7.91E-01	2.24E-01	0.00E+00	0.00E+00

Table 9-7. Comparison of Photon Spectra

(per gram of oxide)

Photon Energy (MeV)	MELOX (gammas/sec)	
	30% PuO_2	8.5% PuO_2
0.014	7.50E+07	2.13E+07
0.021	7.83E-01	3.24E-01
0.028	3.13E+07	8.86E+06
0.060	4.06E+08	1.15E+08
0.077	2.83E+04	8.28E+03
0.101	9.36E+05	2.66E+05
0.118	3.24E+03	9.33E+02
0.147	3.79E+05	1.08E+05
0.210	5.86E+05	1.67E+05
0.333	4.86E+04	1.38E+04
0.389	2.90E+04	8.23E+03
0.560	5.12E+03	1.69E+03
0.664	5.51E+03	1.56E+03
0.770	7.73E+03	2.26E+03
0.980	2.99E+02	9.45E+01
1.598	1.45E+02	5.11E+01
1.915	1.41E+01	5.09E+00
2.615	2.67E+03	9.39E+02
	5.14E+08	1.46E+08

Photon Energy (MeV)	MFFF (gammas/sec)	
	20% PuO_2	5% PuO_2
0.015	4.79E+07	1.20E+07
0.025	7.03E+01	1.76E+01
0.038	4.94E+04	1.23E+04
0.058	1.27E+05	3.17E+04
0.085	1.36E+04	3.40E+03
0.125	4.21E+04	1.06E+04
0.225	5.93E+03	1.57E+03
0.375	2.72E+04	6.80E+03
0.575	1.02E+03	2.55E+02
0.850	1.39E+02	3.47E+01
1.250	1.25E+01	3.13E+00
1.750	5.67E+00	1.42E+00
2.250	3.24E+00	8.14E-01
2.750	1.86E+00	4.67E-01
3.500	1.65E+00	4.13E-01
5.000	6.94E-01	1.74E-01
7.000	7.84E-02	1.97E-02
9.500	8.91E-03	2.24E-03
	4.82E+07	1.20E+07

Table 9-8. Comparison of Neutron Intensities

(per gram of oxide)

	MELOX (neutrons/sec)		MFFF (neutrons/sec)	
	30% PuO_2	8.5% PuO_2	20% PuO_2	5% PuO_2
Spontaneous fission	100.14	28.39	11.8	2.96
Reaction emission (α,n)	149.34	42.32	12.0	3.00
Total	249.48	70.71	23.8	5.96

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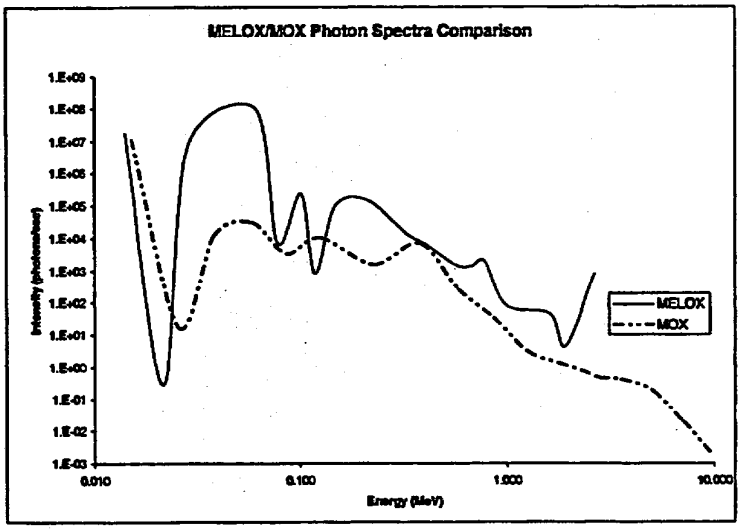

Figure 9-10. MELOX/MFFF Photon Spectra Comparison

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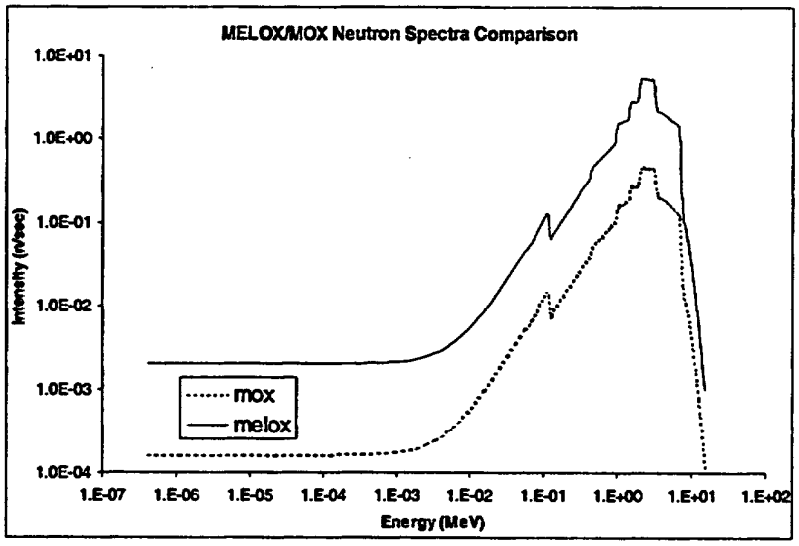

Figure 9-11. MELOX/MFFF Neutron Spectra Comparison

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